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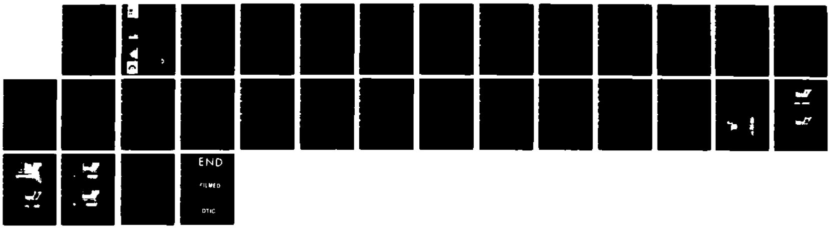

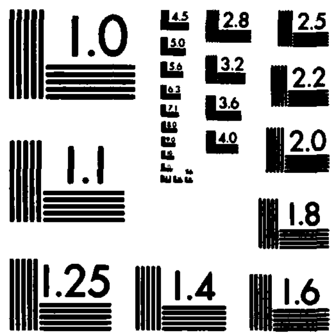


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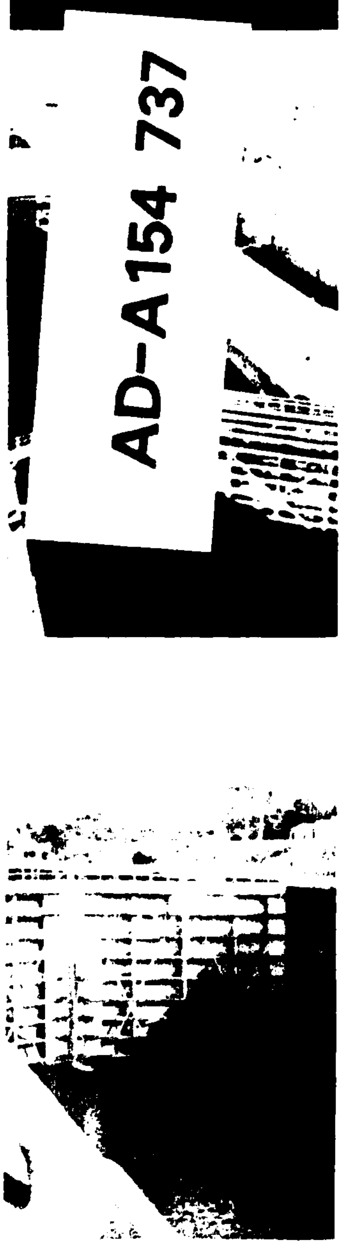


STRUCTURES LABORATORY

MISCELLANEOUS PAPER SL-84-19

# EVALUATION OF EPOXY RESIN SYSTEMS AS BACKING MATERIALS FOR MITER GATES

by

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Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted because of problems encountered with epoxy resin backing material when used as a filler for setting quoin and miter blocks of lock miter gates. The problems were failure of the epoxy system to set and softening after being submerged in water over a period of time.

Laboratory tests were developed to evaluate different epoxy resins when used as a filler for setting quoin and miter blocks of lock miter gates. The

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20. ABSTRACT (Continued):

epoxy resins were tested for effect of curing temperature and thickness on compressibility; effect of curing time on strength; water absorption; effect of moisture on surface hardness; effect of temperature on strength; effect of freezing and thawing on shelf life; flowability in narrow spaces; and compression under water.

Five epoxy resins were tested for the parameters originally requested by the Mobile District. Five more systems were tested for compressive strength, water absorption, and the resistance to softening under water as later requested by the Mobile District. Based on the test results, two systems were found to be the most promising.

## Preface

The investigation described in this report was conducted for the US Army Corps of Engineers, Mobile District, by the Concrete Technology Division (CTD) of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES). Authorization for the investigation was given in DA Form 2544, No. FC-83-0024, dated 28 February 1983.

The investigation was performed under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. John M. Scanlon, Chief, CTD, and under the direct supervision of Mr. Richard L. Stowe, Chief, Materials and Concrete Analysis Group. This report was prepared by Mr. Dennis L. Bean.

Funds for publication of the report were provided from those made available for operation of the Concrete Technology Information Analysis Center (CTIAC). This is CTIAC Report No. 71.

Commander and Director of WES during the investigation and the preparation and publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

## Contents

## Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| Fahrenheit degrees | 5/9 | Celsius degrees or kelvins* |
| inches | 25.4 | millimetres |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per square inch | 6894.757 | pascals |

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

# EVALUATION OF EPOXY RESIN SYSTEMS AS BACKING MATERIALS FOR MITER GATES

## Background

1. The Mobile District has experienced problems with an epoxy resin backing material used as a filler for setting quoin and miter blocks of lock miter gates. ETL 1110-2-133* specifies that an epoxy filler compound similar to the one specified in the ETL or an approved equal be used for that purpose. The Mobile District reports that the epoxy being used has failed to set up and has not performed satisfactorily for various applications. The epoxy appears to be moisture sensitive and it is believed that the properties of the epoxy might be affected by application temperatures or high temperatures over a long period of time. The Mobile District asked the Concrete Technology Division (CTD) of the Waterways Experiment Station (WES) to find other prospective materials and do comparison testing to find the best material for the miter gate applications.

## Objective

2. To determine reasons for the poor performance of the epoxy being used and find sources for other epoxy systems which could be used as a backing material for miter gates.

## Materials, Testing, and Results

3. Five epoxy resin systems were initially tested by WES for evaluation as backing materials for miter gates. Three of the epoxy resins, "A", "B", and "C", were obtained from one formulator, with D and E obtained from two other manufacturers; all the systems were recommended for testing by the Mobile District.

4. "A" is the epoxy resin that is presently being used by the Mobile District. "B" is an experimental epoxy resin recommended for cold weather application. "C" was specially formulated because a thinner version of "B" was

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* Engineering Technical Letter No. 1110-2-133, 2 Aug 1971.

needed to successfully fill narrow spaces. The other two epoxy resins, "D" and "E", were included in the initial test program. The "E" resin was omitted after the testing was started due to the low compressive strength and size of the filler material.

5. Infrared analysis of the resins and hardeners has been made for all the systems. All of the resins are bisphenol-A epicholorohydrin type of epoxies and the hardeners are amines and modified polyamine types. The filler content, epoxy equivalent, and viscosity are shown in Table 1.

Effect of curing temperature
and thickness on compressibility

6. Test specimens were prepared by casting 1-1/2-in.* squares of different thicknesses (1/8, 1/4, 1/2, 1, and 2 in.) from each epoxy resin. The test specimens were cured at temperatures of 35, 50, 70, and 90° F and tested for compressibility (using ASTM C 109-77, "Compressive Strength of Hydraulic Cement Mortars," as guidance) after curing for 8 hr, 1, 2, 3, and 4 days.

7. Each specimen was placed in compression to obtain a stress-displacement curve. A typical curve is shown in Figure 1. The maximum stress value was obtained from these curves and are shown in Tables 2, 3, 4, and 5. The thinner specimens had a higher maximum stress value than did the thicker specimens, the reason being that the end restraint of the steel end platens caused confining pressures in the thin specimens permitting them to sustain higher compressive loads.

8. All of the epoxy resins tested were found to cure slowly at 35° F. Test results indicate that "B" and "C" cured at a faster rate when applied at 35° F and would be the choice for application during low temperatures. At 50° F, all the epoxy resin systems cured at a faster rate than at 35° F, as was expected. Test results indicate that "A", "B", and "C" could be applied at temperatures around 50° F, but at least 2-days curing would be necessary before the gates could be put in operation. At temperatures of 70° F or higher, gates containing the epoxy resins could be put in service after curing for 24 hr.

Effect of curing time on strength

9. Two-inch-diameter by 1/2-in.-thick disks were cast from each of the epoxy resins. The disks were allowed to cure (at 73° F) for 8 hr and 72 hr

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

before being placed in water. The disks were tested in compression after being submerged for 30 and 60 days. The maximum compressive stress and compressive shortening are shown in Table 6.

10. The compressive strengths of the epoxies were not obtained during this phase of the investigation. The relatively thin disks (1/2 in. thick) did not fail under the 55,000-lb applied axial load, i.e., the specimens did not reach a maximum resistance to axial loading.

11. The shortening value for "A", 72-hr cure, 30-day submersion, appears to be in error. This is probably due to a malfunction in the extensometer. There is not a noticeable difference in the displacement values of the 30-day submersion test results when compared to the 60-day submersion test.

Water absorption

12. The fully cured epoxy systems were tested in accordance with ASTM D 570-81, "Water Absorption of Plastics." The test specimens were cast and allowed to cure at room temperature ($73^{\circ}$ F) for one week before being submerged in tap water. The specimens were weighed before being placed in water and reweighed periodically. They were wiped with tissue paper to remove surface water before being weighed. The percent absorbed and the absorption rate are shown in Figures 2 and 2A. "B" and "C" are absorbing less water with time than "A" or "D". This is an indication that these epoxy resins are being less affected by water absorption.

Effect of moisture on surface hardness

13. Diminution of surface hardness is an indication that a material is being softened. Two-inch-diameter by 1/2-in.-thick disks were cast from each of the epoxy resins, one control and one to be submerged in water. The specimens were cured at room temperature ($73^{\circ}$ F) for one week before starting the test (ASTM D 785-65, "Test for Rockwell Hardness of Plastics"). Then the specimens were submerged in water ($73^{\circ}$ F) and tested at specific time intervals. The data suggest that "D" and "A" were more affected by water adsorption than were "B" and "C". The values are shown in Table 7.

Effect of temperature on strength

14. Disks, 1/2 by 2 in., were cast from each of the epoxy resins and were allowed to cure at room temperature ($73^{\circ}$ F) for 72 hr. Disks from all the epoxy resins were placed in an oven at $130^{\circ}$ F with a duplicate specimen also placed in a chamber set at $35^{\circ}$ F. The specimens were exposed to these

temperatures for 30 days, then subjected to 17,500-psi compressive stress. The test results are shown in Table 8. The degree to which the specimens were shortened was not affected by the temperature of exposure.

Effect of freezing
and thawing on shelf life

15. Samples of all the resins and hardeners were stored at 110° F for 37 days. Duplicate samples were cycled at between 10° F and 70° F for 15 cycles. Cylinders, 1-1/2 by 3 in., were cast from each epoxy resin system after each storage condition. The cylinders were allowed to cure at 70° F for one week and tested for compressive strength. The test results are presented in Table 9.

Flowability in narrow spaces

16. A test was designed to determine the flowability of the epoxy resin system into narrow spaces having narrow openings. Molds were made of transparent plastic and wood to contain voids with the dimensions of 1/8 in. thick, 8 in. wide, on the front, and 30 in. deep; 1/8 in. thick, 3 in. wide on one side of the mold, and 30 in. deep; and 1/16 in. thick, 3 in. wide on the opposite side of the mold, and 30 in. deep. The two 3-in. voids (on the sides) were completely open to the 8-in. front void so that the epoxy could flow unimpeded around a corner. The molds were made to simulate the voids found in typical miter blocks of a lock miter gate.

17. A reservoir having dimensions 1-3/8 in. high, 1-1/2 in. wide, and 5 in. long was made to fit on top of the mold. The epoxy was poured into the reservoir so that it could flow directly into the front void. The level of the epoxy in the reservoir was maintained between half full and full. Small batches of epoxy (500 g) were mixed to ensure that the reservoir was at least half full.

18. "C" and "D" flowed completely into the small, narrow space of the mold. The time required to fill the void for "C" was 50 min and 35 min for "D". "B" did not flow into the narrow space very well. It went about 6-1/2 in. into the front void in about 40 min before it began to stiffen. Time-lapse photographs of "C" flowing into the voids are shown in Figures 3a through 3h.

Compression underwater

19. Cylinders, 1-1/2 by 3 in., were cast from systems "B", "C", and "D" being tested and were allowed to cure for one week at room temperature (73° F) before being placed into water. The cylinders were submerged in water at 73° F for 120 days before cyclic testing in compression was started. The testing in

compression under water was accomplished by placing the specimens into a 2-in.-diameter, hollow, polyvinyl chloride (PVC) cylinder that was bonded to a steel platen. The cylinder acted as a water reservoir which allowed the specimen to be tested in compression while it was about 95 percent submerged since there was not a convenient method to test the specimen while it was completely submerged. The depth of the 2-in. PVC cylinder was about 1/8 in. less than the height of the test specimen. The testing was performed assuming 100 percent submersion since the 1/8 in. out of the water should not affect the result significantly. The specimens were compressed underwater to a stressed condition that was 80 percent of the maximum stress value; then, the applied load was immediately released, allowing the specimen to return to an assumed zero stress condition. This loading and unloading was repeated until 100 cycles were achieved. A typical plot showing the deflection after every 25 cycles is shown in Figure 4. Cyclic testing of prewetted specimens submerged in water apparently caused no permanent deformation of the materials tested. The results indicate that the short-term water exposure and short-term cyclic loading did not cause detectable softening of the systems studied.

Acceleration of softening
by elevation of temperature

20. Testing was performed to determine if the resistance to softening under water could be accelerated by continuous submersion at an elevated temperature. Specimens were prepared in the same manner as the specimens for the testing for softening under water at room temperature. After curing the specimens were submerged in water that was maintained at a temperature of $150^{\circ}$ F. Periodically the samples were removed from the hot water, allowed to cool in $70^{\circ}$ F water for 2 hr, and tested for surface hardness. The specimens were tested weekly for 6 weeks. The testing revealed that the submersion at $150^{\circ}$ F did not accelerate the resistance to softening under water.

Survey of other polymer systems

21. After the program began, several other systems, "F", "G", "H", "J", and "K", were selected to be considered as candidate materials. These systems were tested for compressive strengths, percent water absorption, and resistance to softening under water. These new systems exceeded the 12,000-psi limit. "G" was not tested for water absorption because the manufacturer would not send sample. "J" was eliminated from further testing because its working time was not long enough to feasibly apply the material. "H" was softened too much by

moisture and "K" had too much water absorption to be a good candidate material. "F" proved to be the most promising of the five additional systems selected. The water absorption and the resistance to softening under water test are shown in Figure 2A and Table 7.

## Conclusions

22. For the initial project, five epoxy resins, "A", "B", "C", "D", and "E", were to be tested to determine which of the epoxies would be best for use as a backing material for miter gates. Desirable properties needed for epoxy resins used for this purpose are: high compressive strengths, 12,000 psi or greater; flowability into small, thin areas; water absorption; resistance to softening underwater; cure at various temperatures ranging from 35 to 100° F within short curing times, 1 to 2 days; not be affected by cyclic loading underwater, and ease of mixing and application. After the program started, Mobile District requested that more materials be tested but not so extensively. The added materials, "F", "G", "H", "J", and "K", were to be tested only for compressive strength, water absorption, and resistance to softening underwater. The following test results were obtained.

Compressive strength

23. All the epoxies exceeded the compressive strength requirement of 12,000 psi ranging from a low of 15,300 psi to a high of 18,300 psi.

Flowability test

24. "C" and "D" were found to have the best flowability properties. "B" failed the flowability test. "E" was not tested because some of the filler material was larger in diameter than the void to be filled.

Resistance to softening underwater

25. "B", "C", and "F" were less affected by water based on low water absorption values and the surface hardness of test specimens submerged underwater for 156 days.

Rate of cure at various temperatures

26. "B" and "C" were found to cure faster than "A" or "D". All of the epoxies were found to cure at a slow rate at 35° F and based on these tests, none of these epoxies should be applied at temperatures below 40° F unless heat is applied to the metal gates.

Effect of cyclic loading underwater

27. The epoxy resins tested exhibited no permanent deformation when cyclically loaded to 80 percent of their compressive strength underwater when tested for 100 cycles of compressive loads.

Ease of proportioning and mixing

28. All of the products tested can be obtained in kits and can be uniformly mixed using a portable drill and mixing blade.

29. Based on the test results, "C" and "F" were found to be the most promising of the epoxy resins tested for use as a backing for miter gates and were recommended to the Mobile District for future applications of this type.

Table 1

Chemical and Physical Test Results

| Laboratory Identification | Filler Content (percent) | Epoxy Equivalent (WPE)* | Viscosity (cP) |
|---|---|---|---|
| A - Resin | 60.1 | 195 | >100,000** |
| Hardener | -- | -- | 53 |
| B - Resin | 69.7 | 187 | >100,000 |
| Hardener | -- | -- | 53 |
| C - Resin | 65.9 | 190 | 30,000 |
| Hardener | -- | -- | 53 |
| D - Resin | 61.0 | 189 | >100,000 |
| Hardener | -- | -- | 110 |
| E - Resin | † | 193 | |
| Hardener | -- | -- | |

| Laboratory Identification | Compressive Strength, psi |
|---|---|
| A | 18,000 |
| B | 18,300 |
| C | 18,300 |
| D | 15,300 |
| E | 14,000 |
| F | 16,050 |
| G | 18,100 |
| H | 12,680 |
| J | 12,670 |
| K | 13,560 |

* WPE = weight per epoxy equivalent.

** Viscometer could not measure above 100,000 cP.

† Filler supplied separately from resin and hardner.

Table 2

"A" Compressive Strength, psi

| Specimen Thickness, in. | Age | | | | |
|---|---|---|---|---|---|
| | 8 hr | 1 day | 2 day | 3 day | 4 day |
| | | | 35° F | | |
| 1/8 | * | * | * | * | * |
| 1/4 | * | * | * | * | * |
| 1/2 | * | * | * | * | * |
| 1 | * | * | 2,250 | 3,070 | 2,470 |
| 2 | * | 1,360 | 2,260 | 3,160 | 3,890 |
| | | | 50° F | | |
| 1/8 | * | >17,800 | >17,800 | >17,800 | >17,800 |
| 1/4 | * | 11,470 | 16,760 | >17,800 | >17,800 |
| 1/2 | 1,310 | 7,690 | 11,110 | 11,200 | 12,260 |
| 1 | 2,000 | 10,460 | 11,670 | 12,710 | 12,530 |
| 2 | 4,850 | 11,360 | 9,080 | 14,680 | 12,270 |
| | | | 70° F | | |
| 1/8 | >17,800 | >17,800 | >17,800 | >17,800 | >17,800 |
| 1/4 | 15,560 | | >17,800 | >17,800 | >17,800 |
| 1/2 | 15,780 | 17,290 | 17,240 | 16,910 | >17,800 |
| 1 | 16,240 | 17,480 | >17,800 | 17,210 | >17,800 |
| 2 | >17,800 | >17,800 | >17,800 | >17,800 | >17,800 |
| | | | 90° F | | |
| 1/8 | >17,800 | >17,800 | >17,800 | >17,800 | >17,800 |
| 1/4 | >17,800 | >17,800 | >17,800 | >17,800 | >17,800 |
| 1/2 | 17,190 | 16,200 | >17,800 | >17,800 | >17,800 |
| 1 | 17,600 | 15,840 | >17,800 | >17,800 | >17,800 |
| 2 | >17,800 | >17,800 | >17,800 | >17,800 | >17,800 |

* Too soft to test.

Table 3

"B" Compressive Strength, psi

| Specimen Thickness, in. | Age | | | | |
|---|---|---|---|---|---|
| | 8 hr | 1 day | 2 day | 3 day | 4 day |
| | | | 35° F | | |
| 1/8 | * | * | * | * | * |
| 1/4 | * | * | * | * | * |
| 1/2 | * | * | * | 5,820 | 7,110 |
| 1 | * | * | 3,070 | 7,600 | 8,890 |
| 2 | * | * | 2,900 | 7,380 | 11,560 |
| | | | 50° F | | |
| 1/8 | * | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/4 | * | 13,380 | >18,000 | >18,000 | >18,000 |
| 1/2 | * | 7,870 | 14,440 | 14,630 | 16,190 |
| 1 | * | 8,360 | 14,670 | 15,600 | 15,660 |
| 2 | * | 10,000 | 16,690 | 17,370 | >18,000 |
| | | | 70° F | | |
| 1/8 | >18,000 | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/4 | 12,440 | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/2 | 14,150 | 16,640 | >18,000 | >18,000 | >18,000 |
| 1 | 11,380 | 17,160 | 17,870 | >18,000 | >18,000 |
| 2 | 13,090 | >18,000 | 17,330 | >18,000 | >18,000 |
| | | | 90° F | | |
| 1/8 | >18,000 | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/4 | >18,000 | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/2 | >18,000 | >18,000 | >18,000 | >18,000 | >18,000 |
| 1 | >18,000 | >18,000 | 15,560 | >18,000 | >18,000 |
| 2 | >18,000 | >18,000 | >18,000 | >18,000 | >18,000 |

* Too soft to test.

Table 4

"C" Compressive Strength, psi

| Specimen Thickness, in. | Age | | | | |
|---|---|---|---|---|---|
| | 8 hr | 1 day | 2 day | 3 day | 4 day |
| | | | 35° F | | |
| 1/8 | * | * | * | >18,000 | >18,000 |
| 1/4 | * | * | * | 9,040 | 9,780 |
| 1/2 | * | * | 6,050 | 8,890 | 10,310 |
| 1 | * | * | 7,500 | 10,890 | 12,360 |
| 2 | * | * | 9,110 | 12,290 | 12,270 |
| | | | 50° F | | |
| 1/8 | * | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/4 | * | 10,220 | 16,000 | >18,000 | >18,000 |
| 1/2 | * | 7,560 | 12,670 | 16,490 | 15,150 |
| 1 | * | 9,560 | 12,440 | 15,690 | 15,320 |
| 2 | * | 11,780 | 15,110 | 16,840 | 15,290 |
| | | | 70° F | | |
| 1/8 | >18,000 | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/4 | >18,000 | >18,000 | >18,000 | >18,000 | >18,000 |
| 1/2 | 11,870 | 15,820 | >18,000 | >18,000 | >18,000 |
| 1 | 16,180 | 14,000 | 16,440 | >18,000 | >18,000 |
| 2 | >18,000 | 17,100 | 17,510 | >18,000 | 17,730 |
| | | | 90° F | | |
| 1/8 | | | | | |
| 1/4 | | | | | |
| 1/2 | | | | | |
| 1 | | | | | |
| 2 | | | | | |

* Too soft to test.

Table 5

"D" Compressive Strength, psi

| Specimen Thickness, in. | Age | | | | |
| --- | --- | --- | --- | --- | --- |
| | 8 hr | 1 day | 2 day | 3 day | 4 day |
| | | | 35° F | | |
| 1/8 | * | * | * | * | * |
| 1/4 | * | * | * | * | * |
| 1/2 | * | * | * | 5,550 | 5,510 |
| 1 | * | * | * | 6,040 | 5,470 |
| 2 | * | * | * | 5,030 | 6,530 |
| | | | 50° F | | |
| 1/8 | * | * | >15,000 | >15,000 | >15,000 |
| 1/4 | * | 9,330 | 13,840 | >15,000 | >15,000 |
| 1/2 | * | 7,240 | 10,610 | 11,260 | 10,670 |
| 1 | * | 9,050 | 10,770 | 10,810 | 11,510 |
| 2 | * | 10,260 | 11,910 | 12,090 | 11,360 |
| | | | 70° F | | |
| 1/8 | >15,000 | >15,000 | >15,000 | >15,000 | >15,000 |
| 1/4 | 14,220 | >15,000 | >15,000 | >15,000 | >15,000 |
| 1/2 | 11,230 | 14,180 | 14,630 | 14,380 | >15,000 |
| 1 | 12,620 | 13,380 | 14,130 | 14,280 | >15,000 |
| 2 | 13,810 | >15,000 | 14,650 | 14,580 | >15,000 |
| | | | 90° F | | |
| 1/8 | >15,000 | >15,000 | >15,000 | >15,000 | >15,000 |
| 1/4 | >15,000 | >15,000 | >15,000 | >15,000 | >15,000 |
| 1/2 | 13,290 | >15,000 | 14,370 | >15,000 | >15,000 |
| 1 | 13,070 | >15,000 | 14,280 | >15,000 | >15,000 |
| 2 | 13,250 | >15,000 | >15,000 | >15,000 | >15,000 |

* Too soft to test.

Table 6

Compressive Stress Tests

| System | Cure Time, hr | Maximum Compressive Stress, psi | Compressive Shortening, in. |
|---|---|---|---|
| 30-Day Submersion Compressive Stress Test of 1/2-in.-Thick Disk | | | |
| A | 8 | >17,500 | 0.045 |
| | 72 | >17,500 | 0.016 |
| B | 8 | >17,500 | 0.030 |
| | 72 | >17,500 | 0.041 |
| C | 8 | >17,500 | 0.044 |
| | 72 | >17,500 | 0.049 |
| D | 8 | >17,500 | 0.049 |
| | 72 | >17,500 | 0.044 |
| 60-Day Submersion Compressive Stress Test of 1/2-in.-Thick Disk | | | |
| A | 8 | >17,500 | 0.045 |
| | 72 | >17,500 | 0.047 |
| B | 8 | >17,500 | 0.043 |
| | 72 | >17,500 | 0.043 |
| C | 8 | >17,500 | 0.043 |
| | 72 | >17,500 | 0.046 |
| D | 8 | >17,500 | 0.052 |
| | 72 | >17,500 | 0.056 |

Table 7

Rockwell Hardness (M Scale Value)

| System | Control* | Days Submerged 14 | 28 | 56 | 89 | 156 |
|---|---|---|---|---|---|---|
| A | 80 | 75 | 71 | 70 | 69 | 68 |
| B | 92 | 93 | 93 | 93 | 93 | 90 |
| C | 91 | 90 | 91 | 90 | 91 | 89 |
| D | 91 | 89 | 89 | 87 | 86 | 85 |
| F | 82 | 79 | 80 | 80 | 80 | 79 |
| G | 83 | 84 | 86 | 90 | ** | ** |
| H | 82 | -- | 78 | -- | -- | 76 |
| J | 73 | -- | 72 | 73 | -- | 70 |
| K | 84 | -- | 80 | † | † | 76 |

* Measured after curing for 21 days in laboratory air, 73$^{o}$ F.

** Stopped testing because value increased.

† Not tested because of poor results on absorption test.

Table 8

Shortening Due to Compressive Stress of 17,500 psi After Exposure for 30 Days to Each of Two Temperatures

| System | Temperature, °F | Compressive Shortening, in. |
|---|---|---|
| A | 35 | 0.058 |
| | 130 | 0.049 |
| B | 35 | 0.038 |
| | 130 | 0.040 |
| D | 35 | 0.050 |
| | 130 | 0.056 |

Table 9

Effect of Freezing on Shelf Life

| | Compressive Strength, psi | |
|---|---|---|
| System | Cylinders Made from Materials Cycled from 10-70 F for 115 Cycles | Cylinders Made from Materials Stored at 110 F for 37 Days |
| A | 17,750 | 17,760 |
| B | 17,750 | 18,400 |
| D | 14,100 | 14,120 |

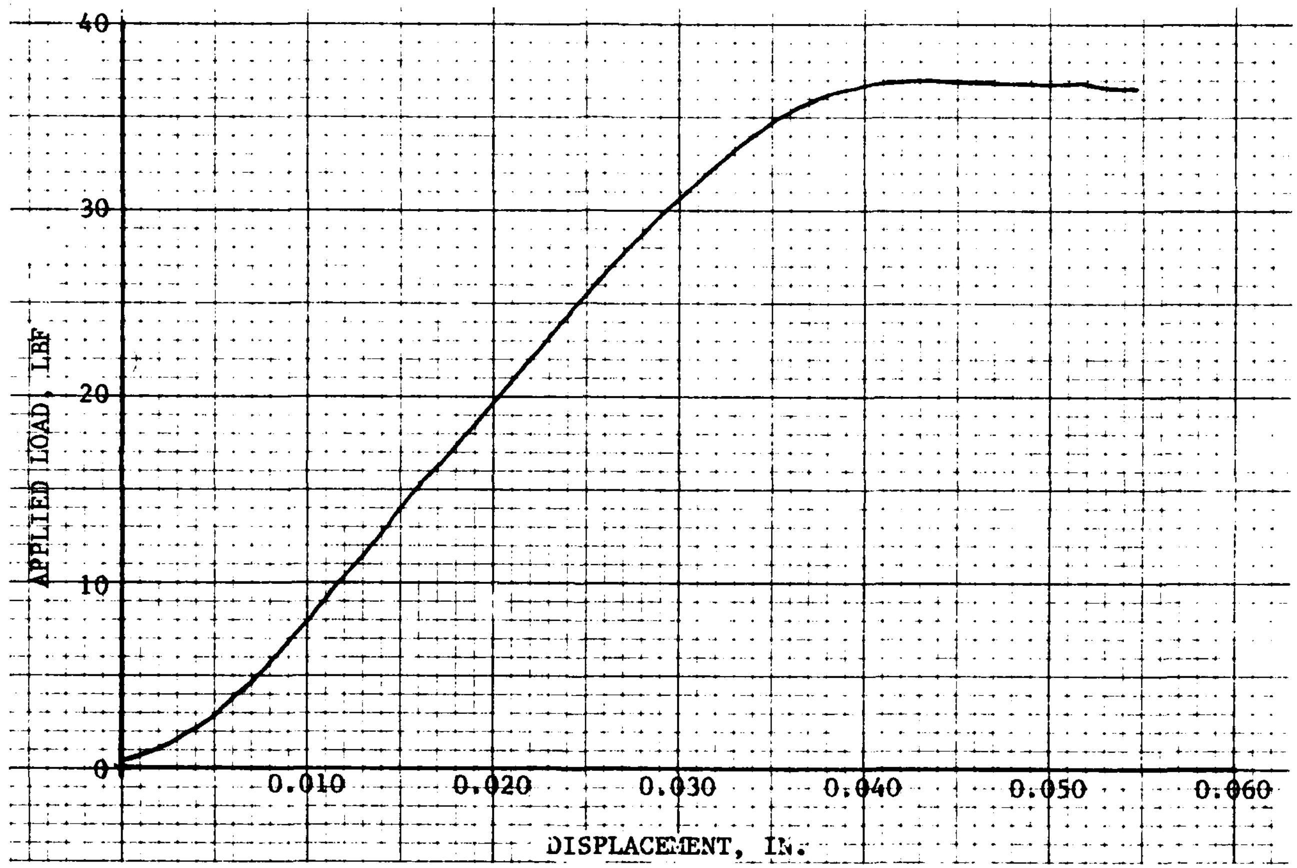



Figure 1. Typical stress-displacement curve ("A", 1/2 in. thick, $70^{\circ}$ F, 1 day)

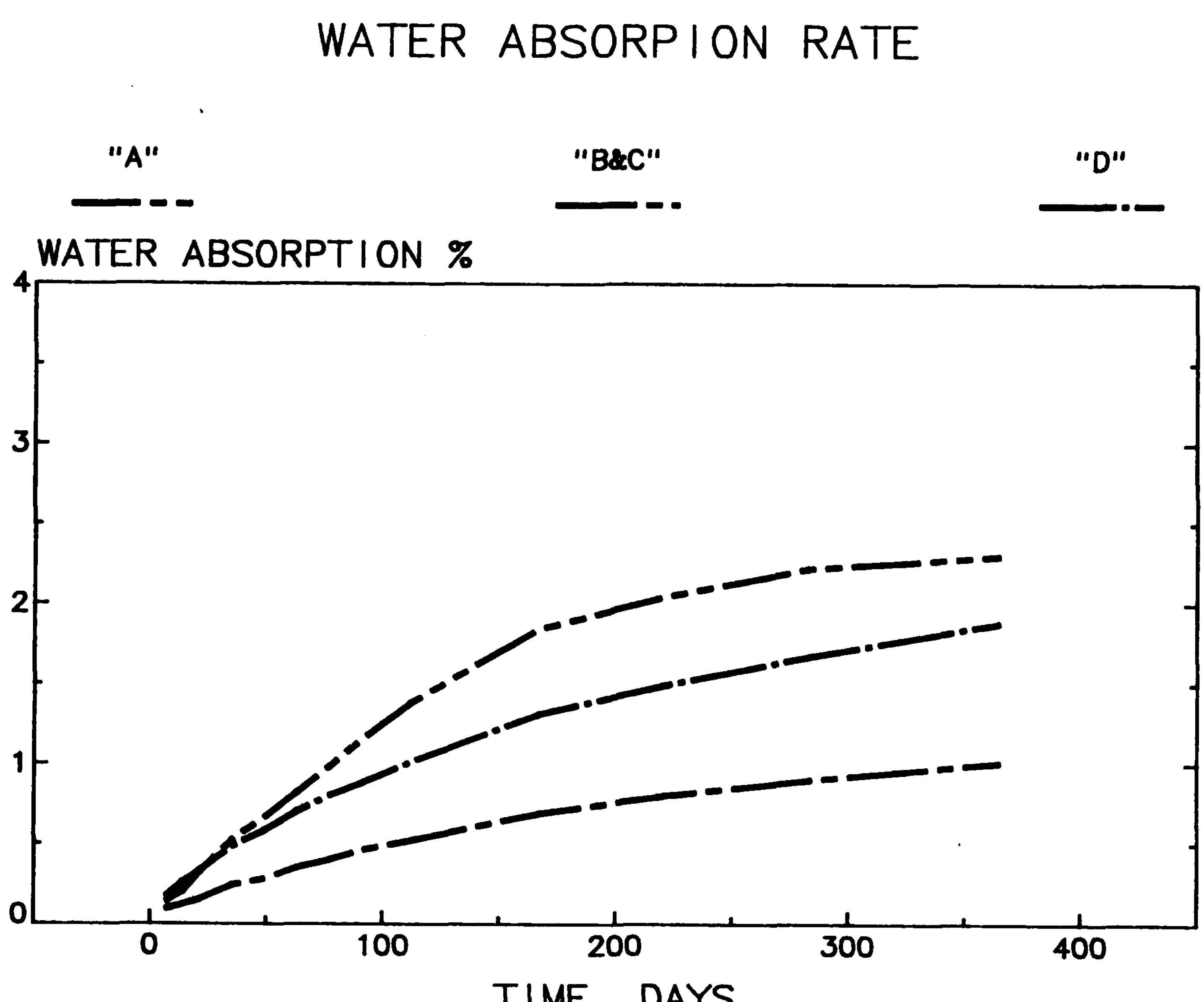



Figure 2. Water absorption rate

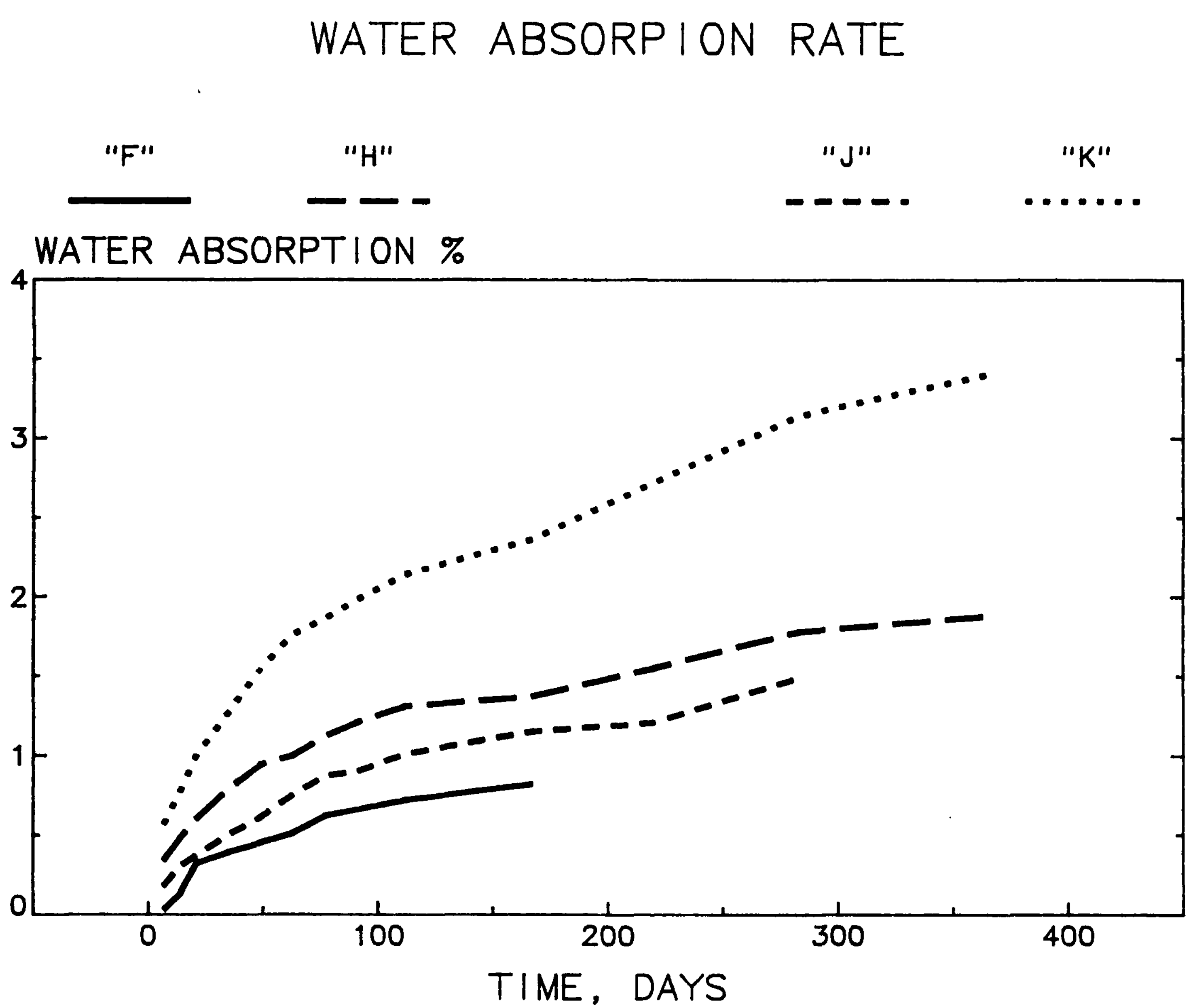
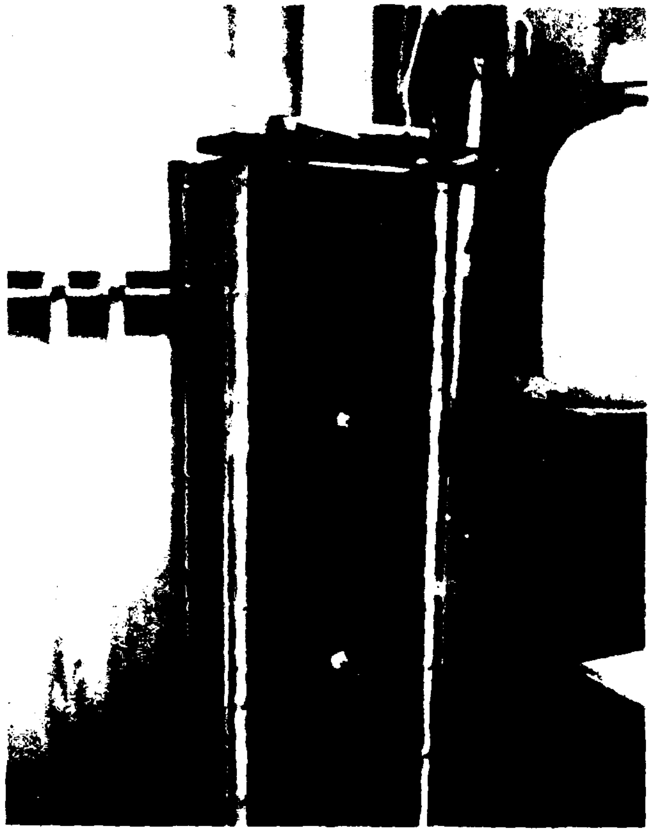



Figure 2A. Water absorption rate



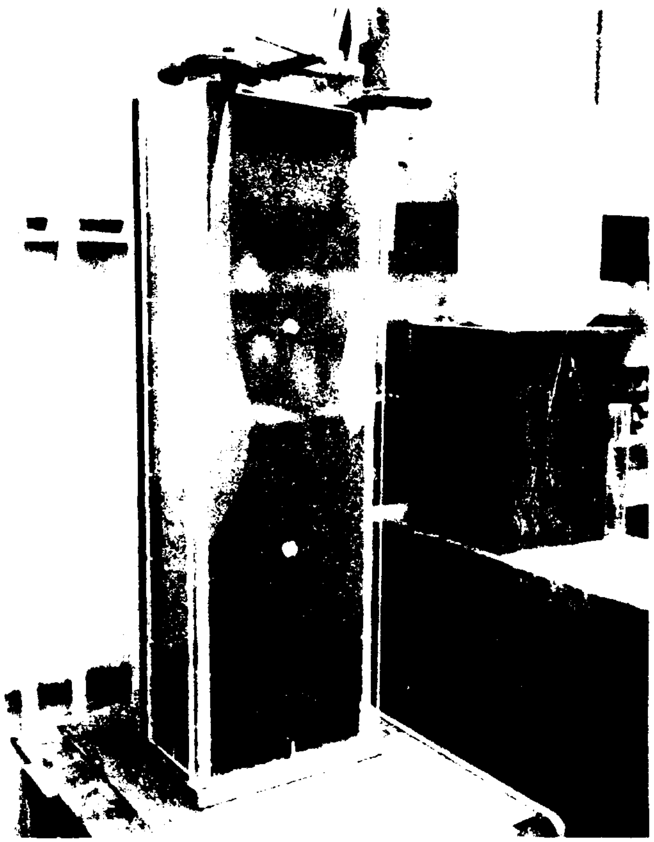
5 Minutes

a. "C", front and left, 1/8 in. thick

10 Minutes

b. "C", front, 1/8 in. thick

Figure 3. Flowability in narrow spaces



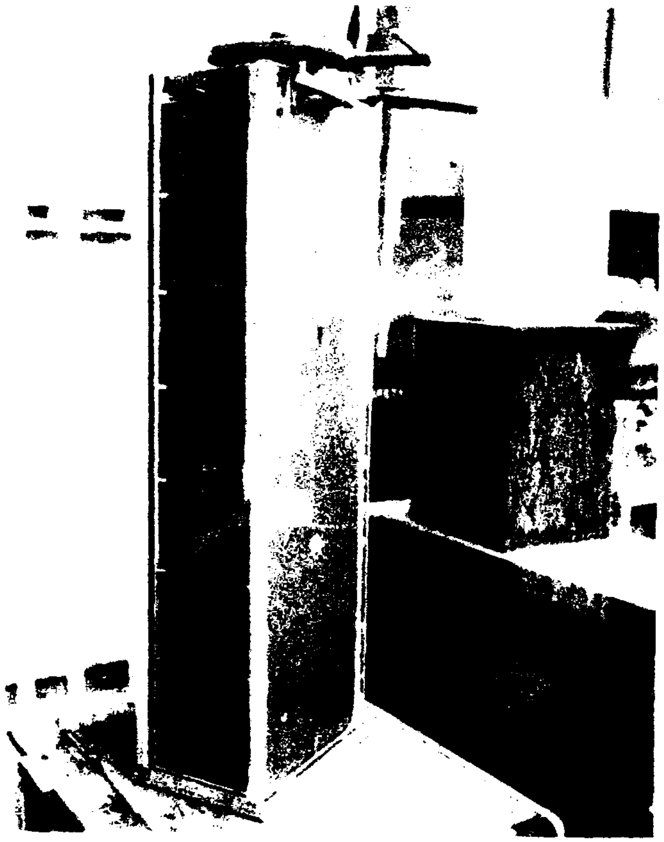
15 Minutes

c. "C", front, 1/8 in.

20 Minutes

d. "C", front and side, 1/8 in.

Figure 3. (Continued)



25 Minutes

e. "C", side, 1/8 in.

25 Minutes

f. "C", side, 1/16 in.

Figure 3. (Continued)

30 Minutes

g. "C", side, 1/16 in.

35 Minutes

h. "C", side, 1/16 in.

Figure 3. (Concluded)

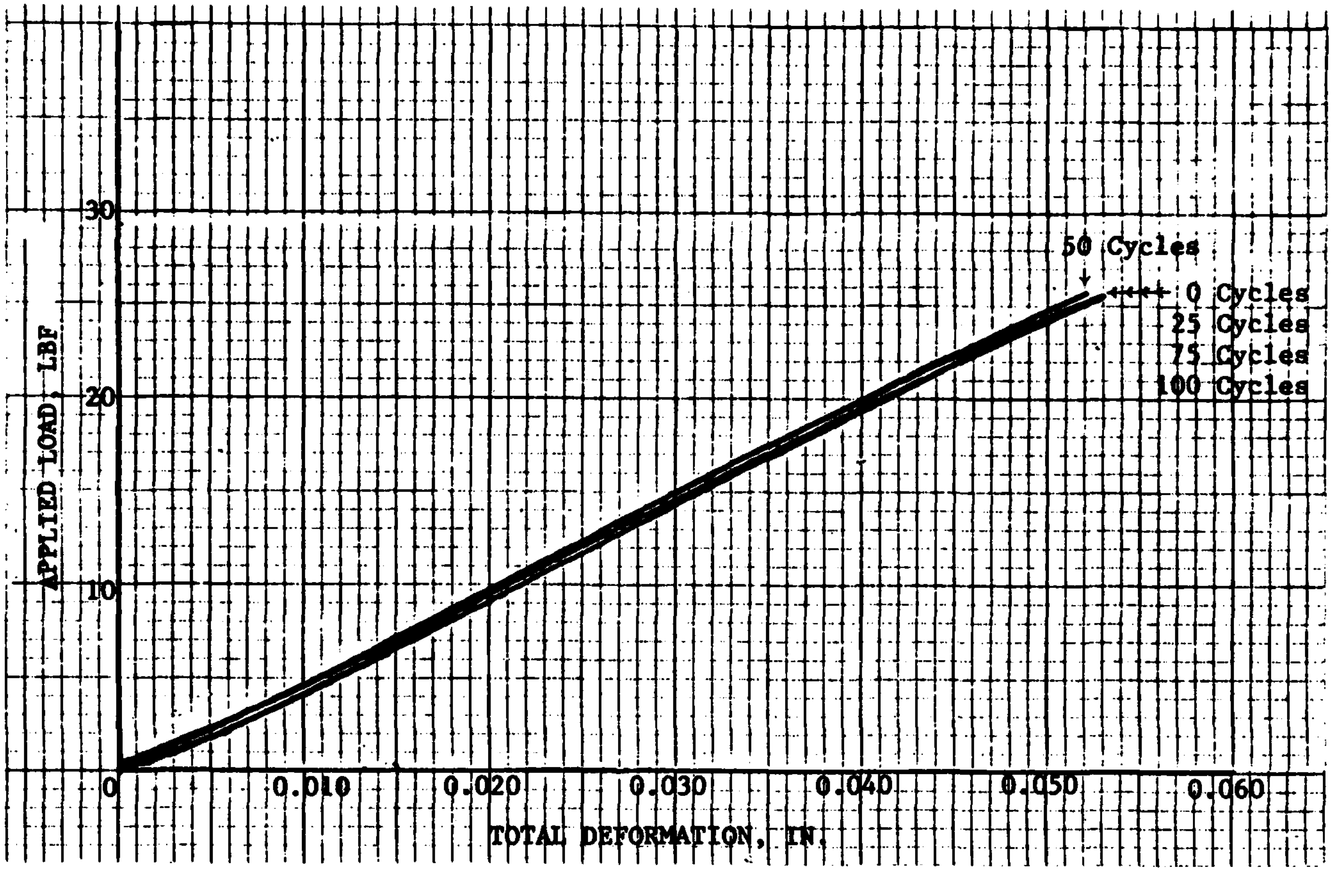



Figure 4. Deformation during underwater cyclic testing in compression of "C"

END

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